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Bendix
Navigation & Control Division

N74-25924

MULTIFUNCTION DISPLAY SYSTEM

FINAL REPORT

PREPARED FOR:

GEORGE C. MARSHALL
SPACE FLIGHT CENTER
NATIONAL AERONAUTICS
AND SPACE
ADMINISTRATION

CONTRACT NUMBER:
NAS8-27564

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PREPARED BY:

THE BENDIX
CORPORATION

NAVIGATION AND
CONTROL DIVISION

TETERBORO, N.J.

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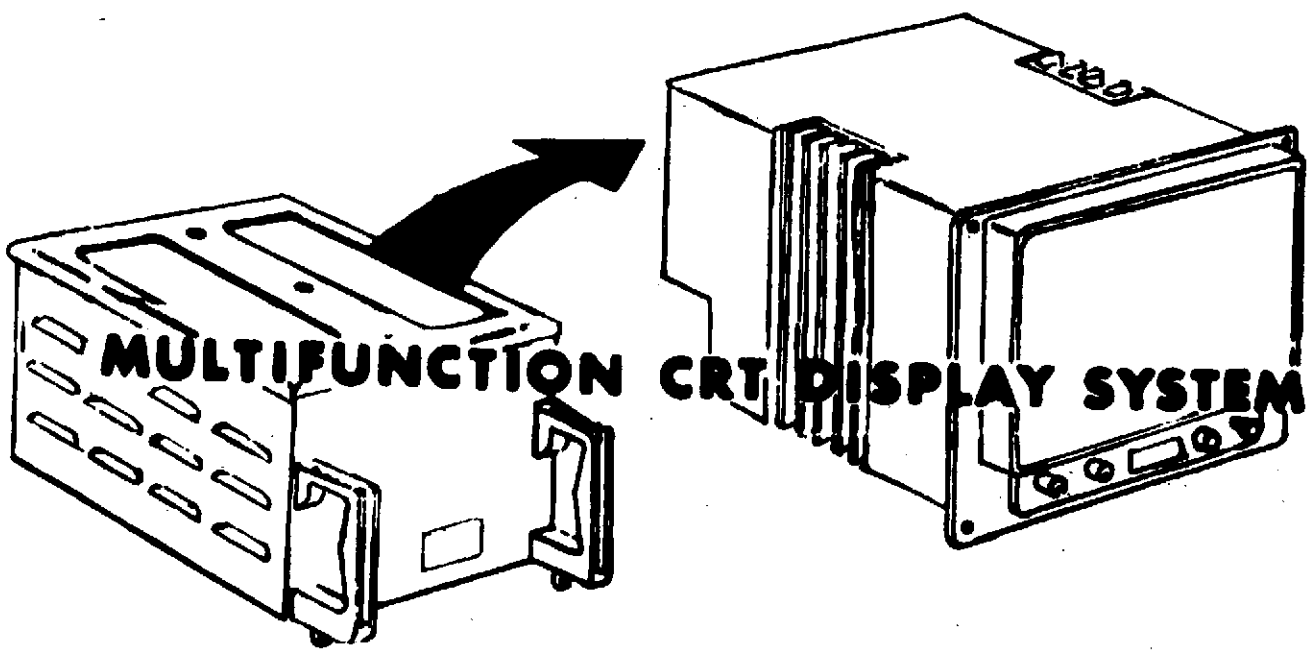
PRICES SUBJECT TO CHANGE

MULTIFUNCTION DISPLAY SYSTEM

FINAL REPORT



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ABSTRACT

This Final Report documents and summarizes the results of Contract NAS8-25764 for design, manufacture, test, and delivery one each Multifunction Display System. This system consists of a programmable Symbol Generator, CRT Display Indicator, Function Keyboard, and Data Terminal Simulator/Input Loader. Delivery and checkout at MSFC, Huntsville, Ala. was completed in July 1973.

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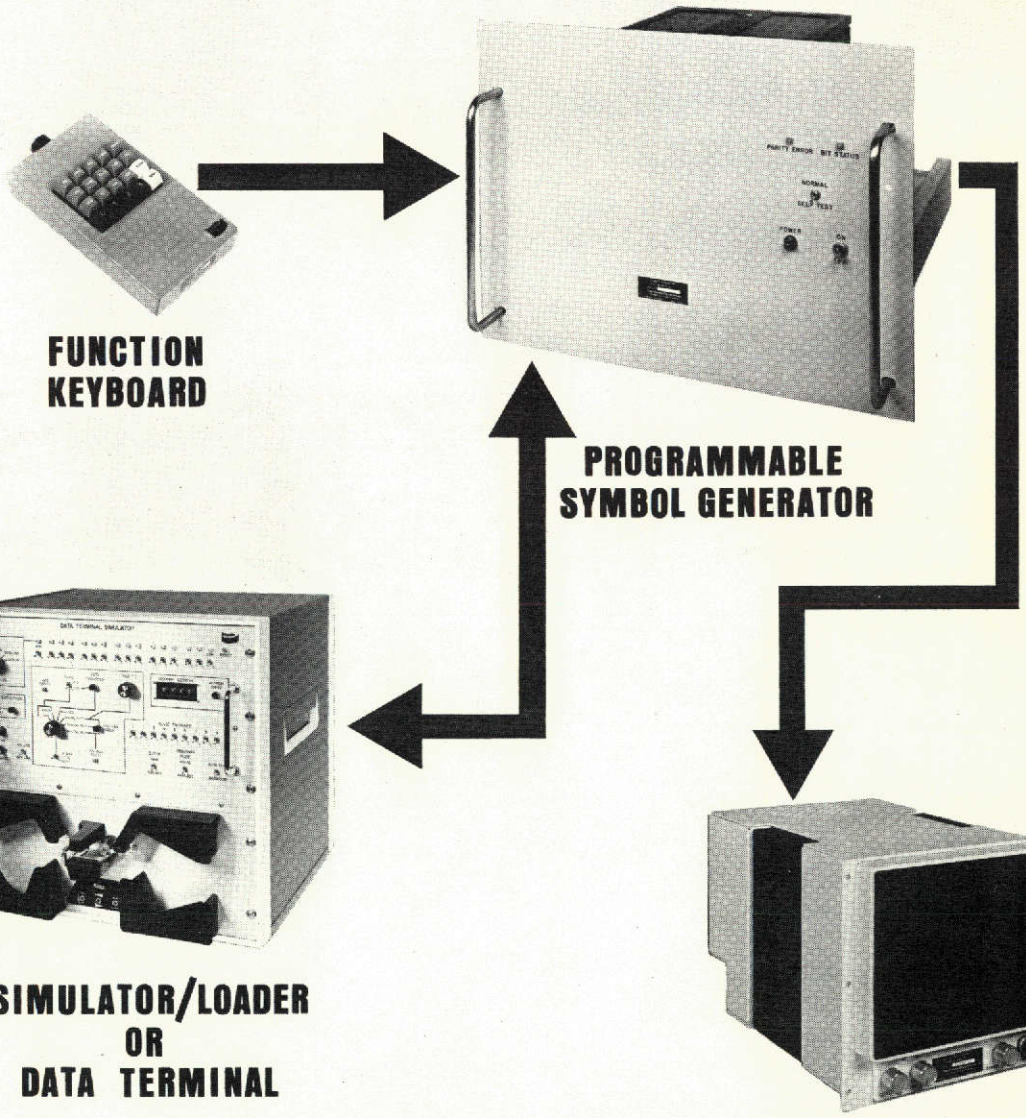
MULTIFUNCTION CRT DISPLAY SYSTEM



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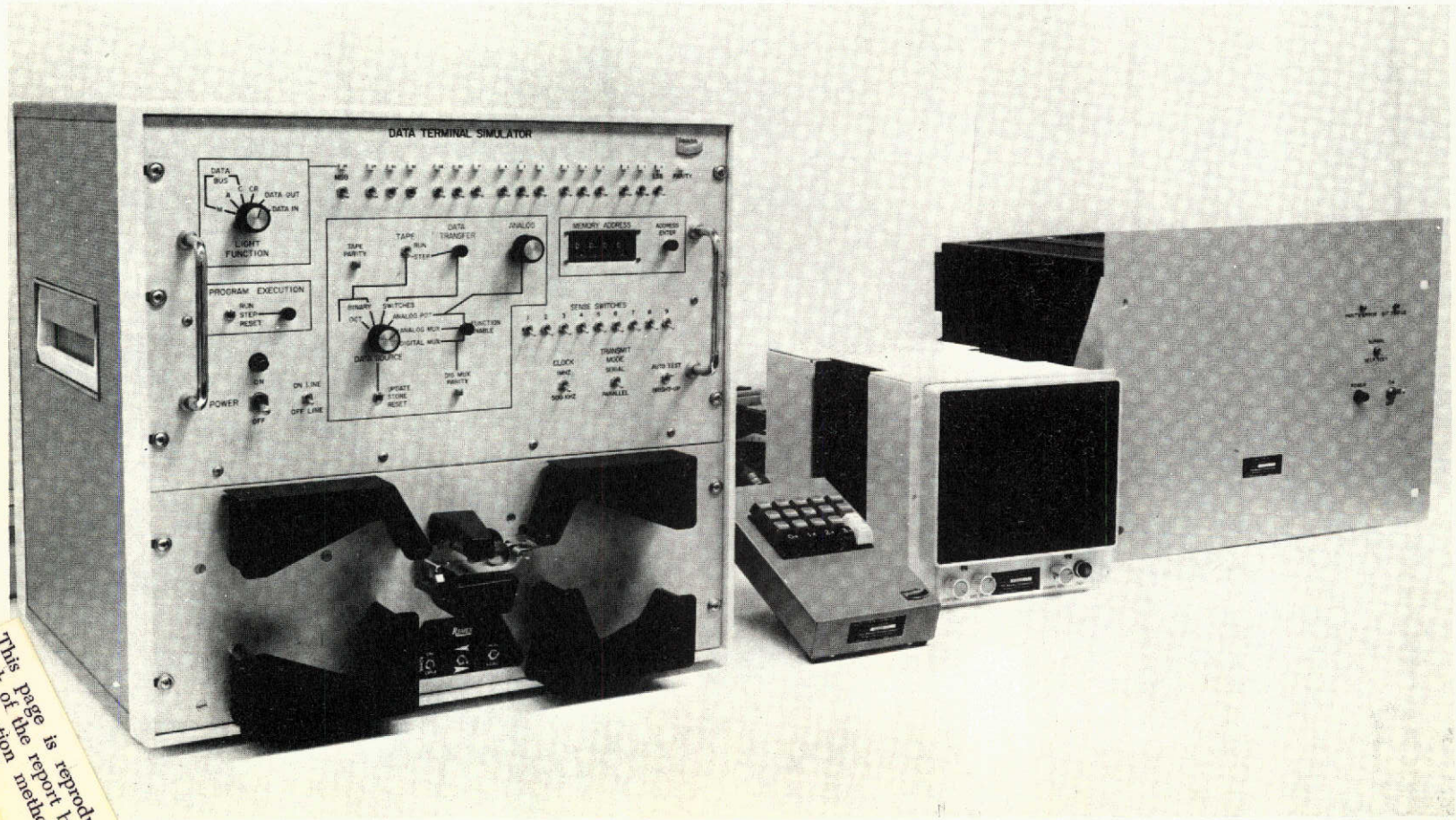

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Programmable Multifunction
CRT Display System
Figure 1-1

SECTION 1
INTRODUCTION

1.1 SCOPE

This Final Report is prepared by the Navigation and Control Division of The Bendix Corporation, Teterboro, New Jersey for the George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Alabama in accordance with paragraph 4.2, Exhibit A of Contract No. NAS8-25764. This report documents work performed to requirements outlined in Exhibit A of the subject contract as initially defined and as later expanded under Contract Modification No.5.

1.2 PURPOSE

In order to successfully operate spacecraft subsystems or experiments an increasingly large number of complex parameters and functions must be observed and interpreted during all phases of the mission. Further, it seems most desirable to concentrate this information in an area immediately within the field of view of the operator. Since various parameters have different orders of importance for different mission phases, it is difficult to place all dedicated instruments at their optimum location on the C and D panel. To alleviate this problem there is a need for a multifunction CRT display which will present different information during different mission phases to the crew at centralized locations.

This contract is for the design, manufacture, test, and delivery of a Multifunction Display System which can satisfy the general needs described above.

1.3 ITEM DESCRIPTION

The Multifunction Display System is a general purpose, time-shared, electro-optical display driven by onboard data management systems. It is capable, in the most flexible manner, of presenting information of many forms. The displays could consist of alphanumerics, symbolics, graphics, separately or in combination. The most distinguishable feature of a multifunction display is its flexibility.

The display formats may include such varied forms as instruction lists, thermometer type scales, moving tapes, graphs, tables, or maps. As indicated in Figure 1-1, from left to right, the Programmable Multifunction Display System (PMDS) consist of:

Data Terminal Simulator/Input Loader
Keyboard Controller
CRT Display Indicator
Programmable Symbol Generator

The Data Terminal Simulator/Input Loader is not considered a part of a flight version of this display system. This unit operates as an interface simulator for memory loading, updating, and for system testing.

1.4 ACCOMPLISHMENTS

The Multifunction CRT Display System was delivered to MSFC, Huntsville, Alabama early in July 1973. Initial checkout was performed at that time. Each display format as described in the statement of work was successfully demonstrated. Documentation including a maintenance manual, programmers manuals and software design manuals were delivered in August 1973. At present, the equipment is being integrated within the shuttle payload simulation facility.

1.5 APPLICABLE DOCUMENTATION

NASA MSFC DOCUMENTS

Contract NAS8-27564 with Modifications
40M35746 Data Bus Interface.

BENDIX CORPORATION DOCUMENTS

Minutes of Preliminary Design Review
Minutes of Critical Design Review
Monthly Progress Reports
Model 912 Indicator Operation and Maintenance Manual
Programmers Reference Manual - Assembly Level
Programmers Reference Manual - Machine Level
Multifunction Display System Operation and Maintenance Manual
HSI - Approach Mode Software Program
MACH -Altitude Mode Software Program
EADI Mode Software Program
Vertical Scale Software Program
Diagnostics Software Program
Assembler and Card to Tape Software Program.

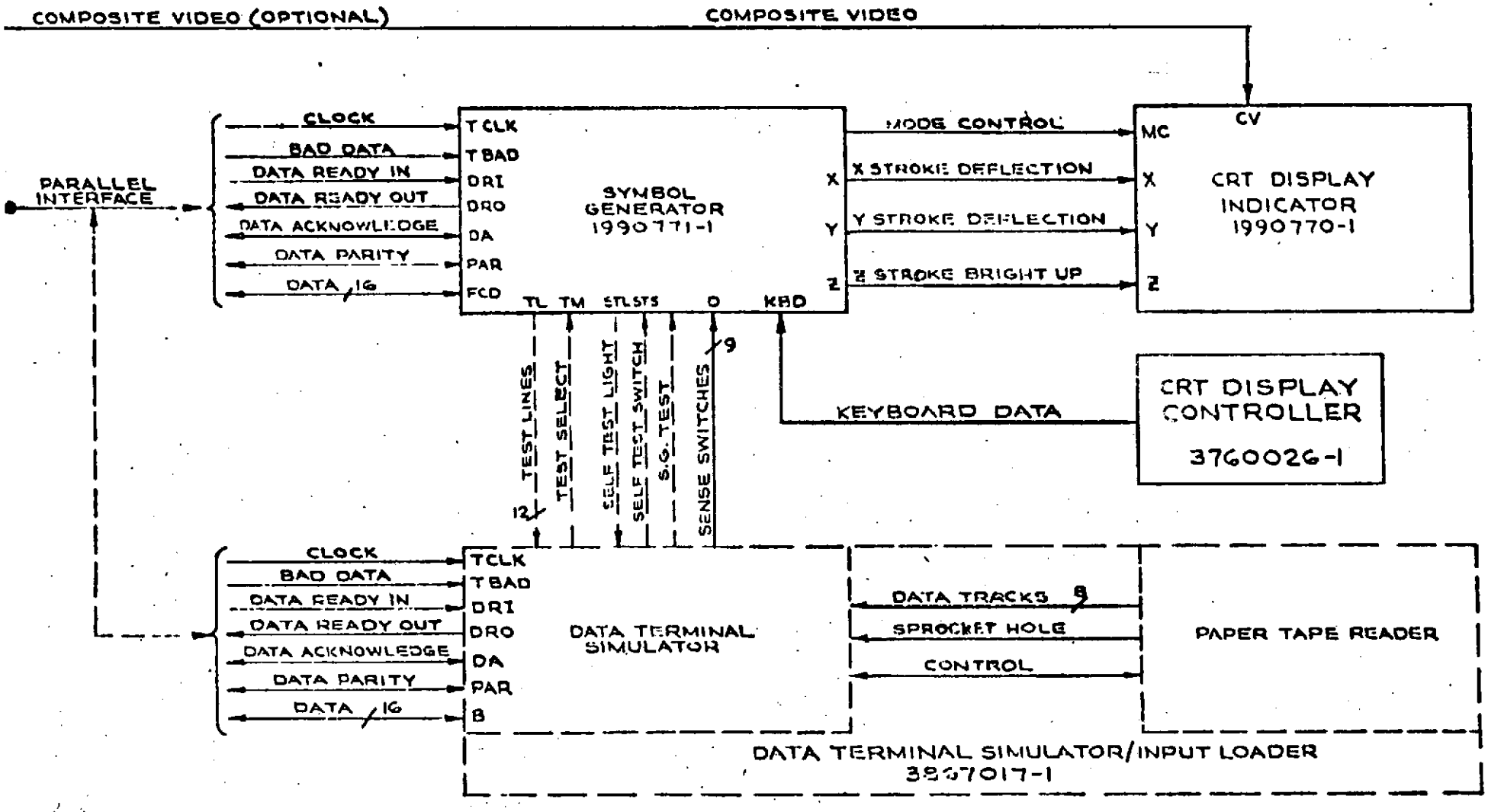
SECTION 2
EQUIPMENT DESCRIPTION

2.1 GENERAL

This section offers a brief description of the Multifunction CRT Display hardware. System operation is treated first, followed by a description of each of the four major subassemblies. For greater detail the reader is referred to the "Multifunction Display System - Operation and Maintenance Manual."

2.2 SYSTEM OPERATION

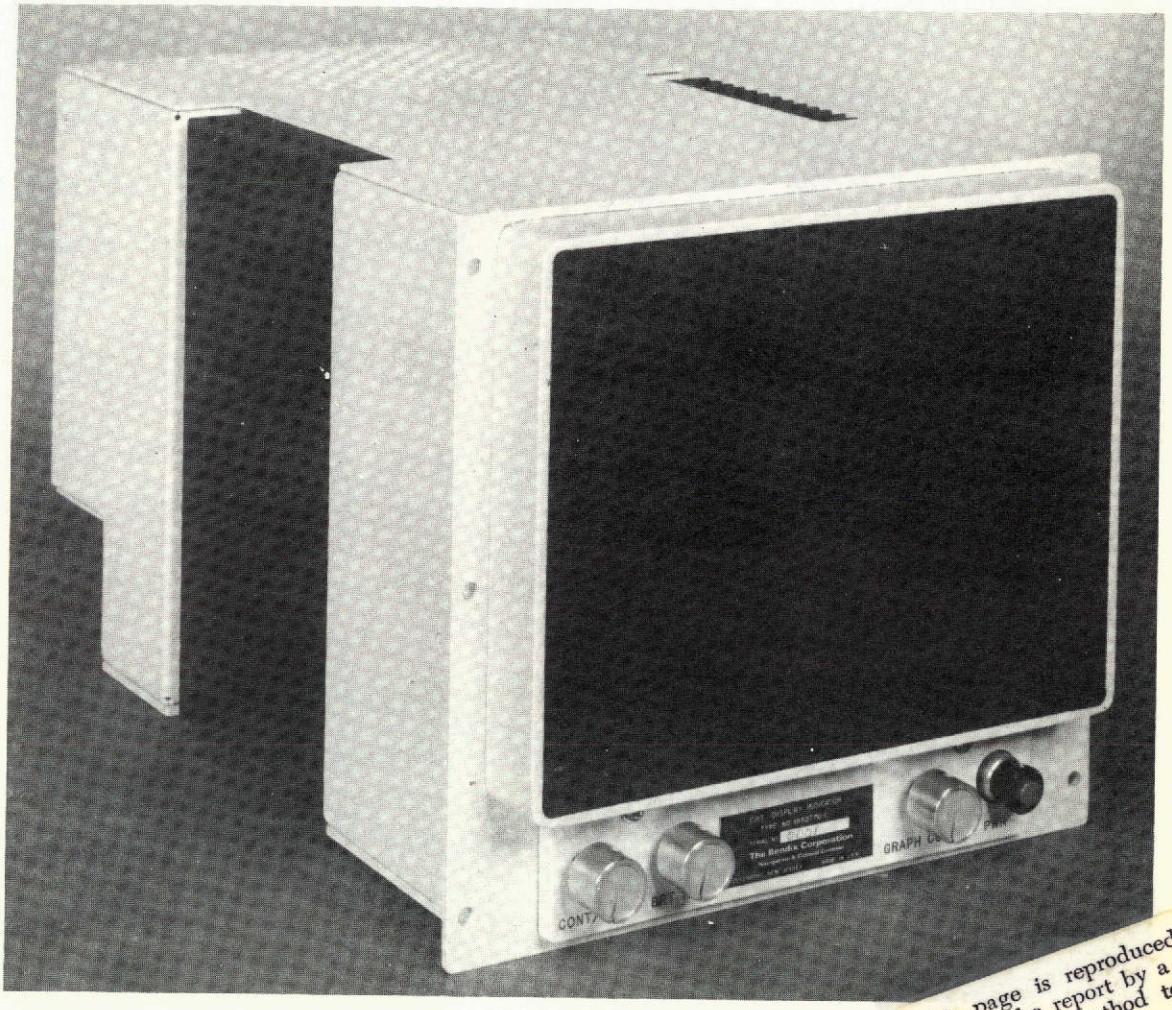
The PMDS, consisting of a Display Indicator, a Symbol Generator and a Display Controller, is interconnected as shown in the block diagram, Figure 2-1. The Indicator accepts 400Hz, 115V, single phase power and has an independent power switch on the front panel. Composite video, if displayed, is connected to the Indicator on a 75 ohm coaxial connector. All other system connections are made to the Generator on 75 ohm coaxial cables. These signals are X, Y, Z, and Mode. The Indicator has the capability to display either the stroke written symbology or a 525 line TV picture, with or without stroke symbols in the vertical retrace. Operator adjustment of brightness, TV contrast, and stroke contrast can be performed with the front panel controls of the Indicator.



SYSTEM BLOCK DIAGRAM
FIGURE 2-1

The Programmable Symbol Generator contains the circuits for drawing the symbology and driving the indicator. The signals for the indicator exit the generator on the rear panel connector. The Generator also contains the interfacing to provide interactive program selection from the Operators Keyboard Controller to the computer main memory. The rear panel connector J1, is divided into two sections. The A side provides a serial or parallel interface to the computer via a Data Terminal on twisted, shielded wires as described in the Shuttle Breadboard Control and Display/Data Bus Interface Definition Document No. 40M35746. The B side contains the signals from the Controller, as well as the test lines to the Simulator. The front panel of the Generator has operator controls for power for both the Generator and Controller, and for selecting and monitoring the self testing functions of the Generator.

The CRT Display Keyboard Controller has a twenty button keyboard that the operator uses for selecting a desired program from the computer memory. As the operator is selecting the program, the legend from the button that is pushed is displayed at the bottom center of the CRT. When the selection is complete, the computer takes a program code and transfers that format back to the generator memory for execution. The Generator will continue to draw that format updating it with new data as it is supplied, until another format is selected.



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CRT Display Indicator

Figure 2-2

2.3 CRT DISPLAY INDICATOR

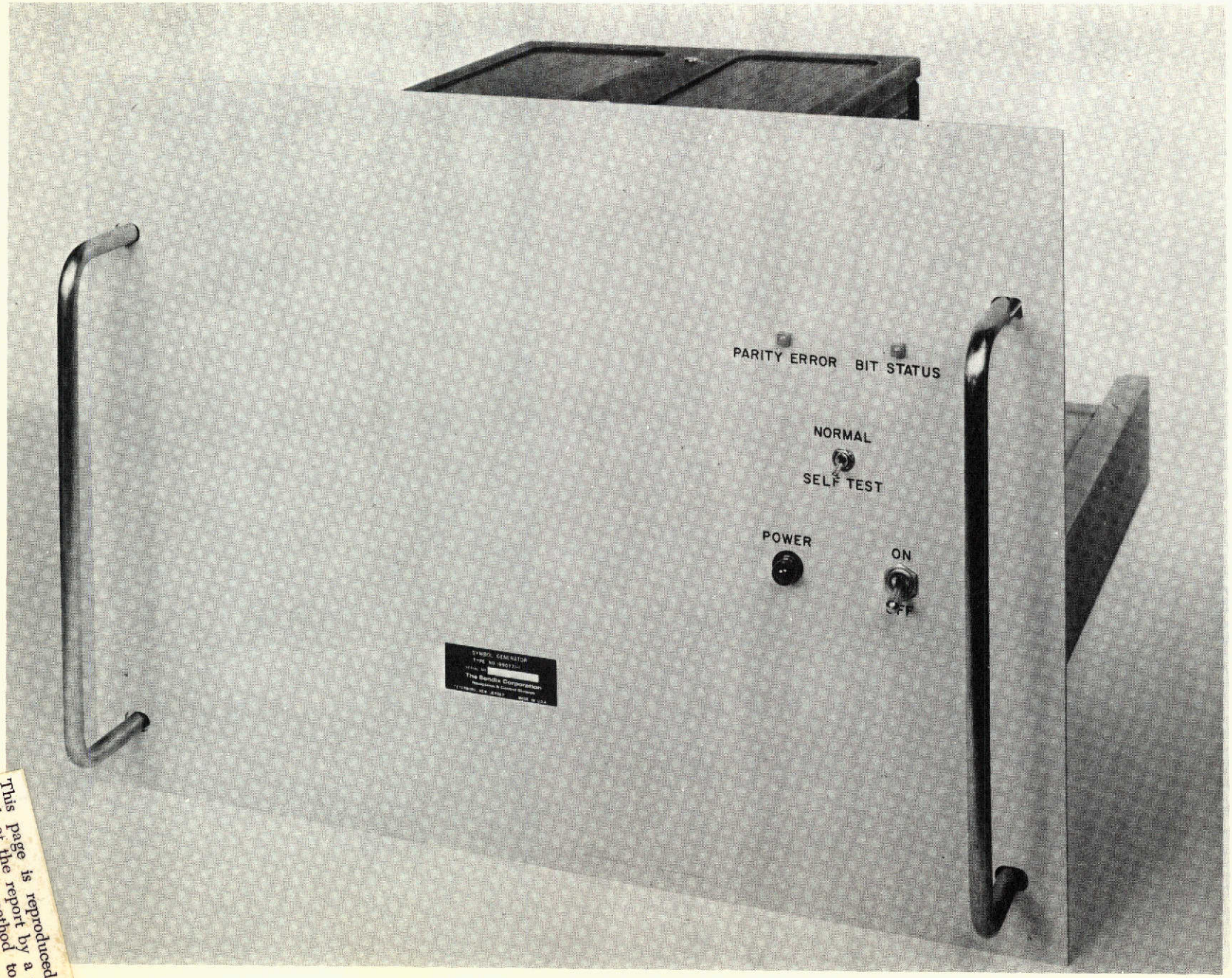
2.3.1 GENERAL

The CRT Display Indicator interfaces with the Symbol Generator to present the desired program information to the flight crew. The display may be used as an XYZ display (stroke writing), as a TV monitor or for stroke writing in the vertical retrace time of the TV raster. A mode switch on the rear panel controls the mode of operation. In the stroke mode, the Symbol Generator provides the horizontal and vertical deflection and the video for the display. In the raster mode the display accepts a composite video signal and generates the appropriate deflection waveforms. The vertical retrace time of the raster is decoded and sent to the Symbol Generator. This signal initiates the stroke writing, if any writing is to be done during the retrace.

The CRT Display Indicator is a self-contained unit which includes deflection amplifiers, video amplifiers, linearity correction, CRT protection and all necessary low voltage and high voltage power supplies. The CRT Display Indicator is capable of accepting stroke and raster deflection signals. The useful screen area is a 5" x 7" format.

2.3.2 MAJOR CHARACTERISTICS

Display Type	Stroke, Raster or Combined
Refresh Rate	60Hz
Writing Rate	100,000 in/sec
Input Signals	
X Deflection	±5V FS, positive to left
Y Deflection	±3.675V FS, positive down
Z Video	2V (Bright)
Input Impedance	75 ohm
Deflection Characteristics	
Positioning Accuracy	±1% of Full Scale
Positioning Repeatability	0.1% of Full Scale
Positioning Time (Random)	30 μ sec max
Bandwidth, Video	10 MHz
Display Characteristics	
Useful Screen Area (Nominal)	5" x 7"
Contrast Ratio (at 200 FL)	10:1
Phosphor Color	P4 (White)
Volume	9.0"w x 8.75"h x 14.3"d
Weight	30 lbs.
Power Dissipation	78 watts



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Programmable Symbol Generator

Figure 2-3

2.4 SYMBOL GENERATOR

2.4.1 GENERAL

The Symbol Generator provides CRT deflection signals to the X and Y deflection amplifiers and Z axis bright-up circuit so as to produce stroke symbols and characters on the face of the CRT. The symbology is generated and positioned in response to signals from external sources. The symbology is repeated at a refresh rate of 60 Hz to give the illusion of a continuous presentation. The programmable Symbol Generator provides this function with the unique advantage of the entire display programmable via software. Software is loaded into the semiconductor Random Access Memory from the computer interface.

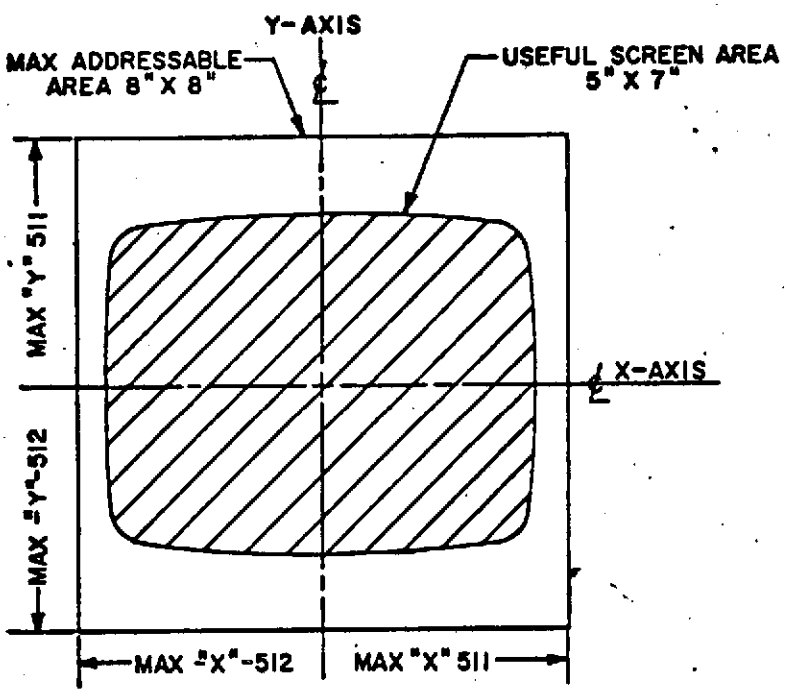
The Symbol Generator design features a hybrid approach to symbol generation. The symbology is digitally derived; all processing, storing, positioning, and control functions are accomplished using digital techniques. The X and Y deflection waveform generation uses analog techniques. All symbols are written at the same writing rate regardless of size or shape. This provides a uniform intensity display over the entire useful screen area.

The writing techniques employed provides an adaptive symbol write and slew delay time to maximize the amount of symbology possible for a given writing rate. The delay is to afford time for the deflection system to position the CRT spot at the proper starting location.

A choice of two slew delays, under software control, are provided. A short slew delay of 5 μs can be used for symbols nearly adjacent. A long delay of 40 μs can be provided for symbols spaced more than 10% of screen area away.

The manner in which the Symbol Generator is organized is unique. All displays are determined by the contents of the main memory and commands from external sources. A great deal of flexibility exists to modify, add or delete the symbology desired. Nearly any display which consists of a line, vector, circle, or alpha-numeric individually or in combination, can be made using the Symbol Generator. The contents of the memory (software), which store instructions and positioning information, are the only components specifically designed for a given display. All other hardware is designed for general application and is not dedicated to a specific symbology requirement.

The display system has a useful screen area divided into 1024 x 1024 addressable locations, corresponding to a 10 bit x 10 bit system. The symbology is drawn on an 8" x 8" square matrix as shown below. Note that the useful screen area is nominally a 5" x 7" region.



USEFUL SCREEN AREA

FIGURE 2-4

2.4.2 MAJOR CHARACTERISTICS

Symbol Generation Technique	Stroke
Refresh Rate	60 Hz
Addressable Screen Area	8" x 8"
Useful Screen Area (Nominal)	5" x 7"
Writing Rate	100,000 in/sec
Generator Organization	Programmable
Data Input	Digital, Parallel or Serial
Clock Rate	1MHz
Update Rate	50,000 Word/Sec
Data Format	16 Bits + Parity
Parity	Odd
Internal Control Word	Digital, Parallel
Word Size	12 Bit
Memory	Semiconductor
Total Capacity	4096 Words
Type (mix of)	ROM/RAM
Word Size	12 Bit
Instruction Set	28 Operations
Memory Referenced	6
Accumulator-Register	17
Auxiliary Registers	16
Input/Output	2
I/O Addresses	16
Control Operations	3

Symbol Set	
Position	
Addressable Locations	1024 x 1024
Vectors	
Choice of Length	1024
Choice of Angle	1024
Alphanumerics	
Repertoire	Full ASCII Set
Choice of Sizes	4
Circles	
Choice of Diameter	512
Coordinate Rotation	
Choice of Angles	1024
Bright Up Limits	4
Choice of Position (each)	1024
Bite Provisions	
Automatic Self Test	60 times/second
Manual Self Test Display	As required

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Keyboard Controller

Figure 2-5

2.5 KEYBOARD CONTROLLER

2.5.1 GENERAL

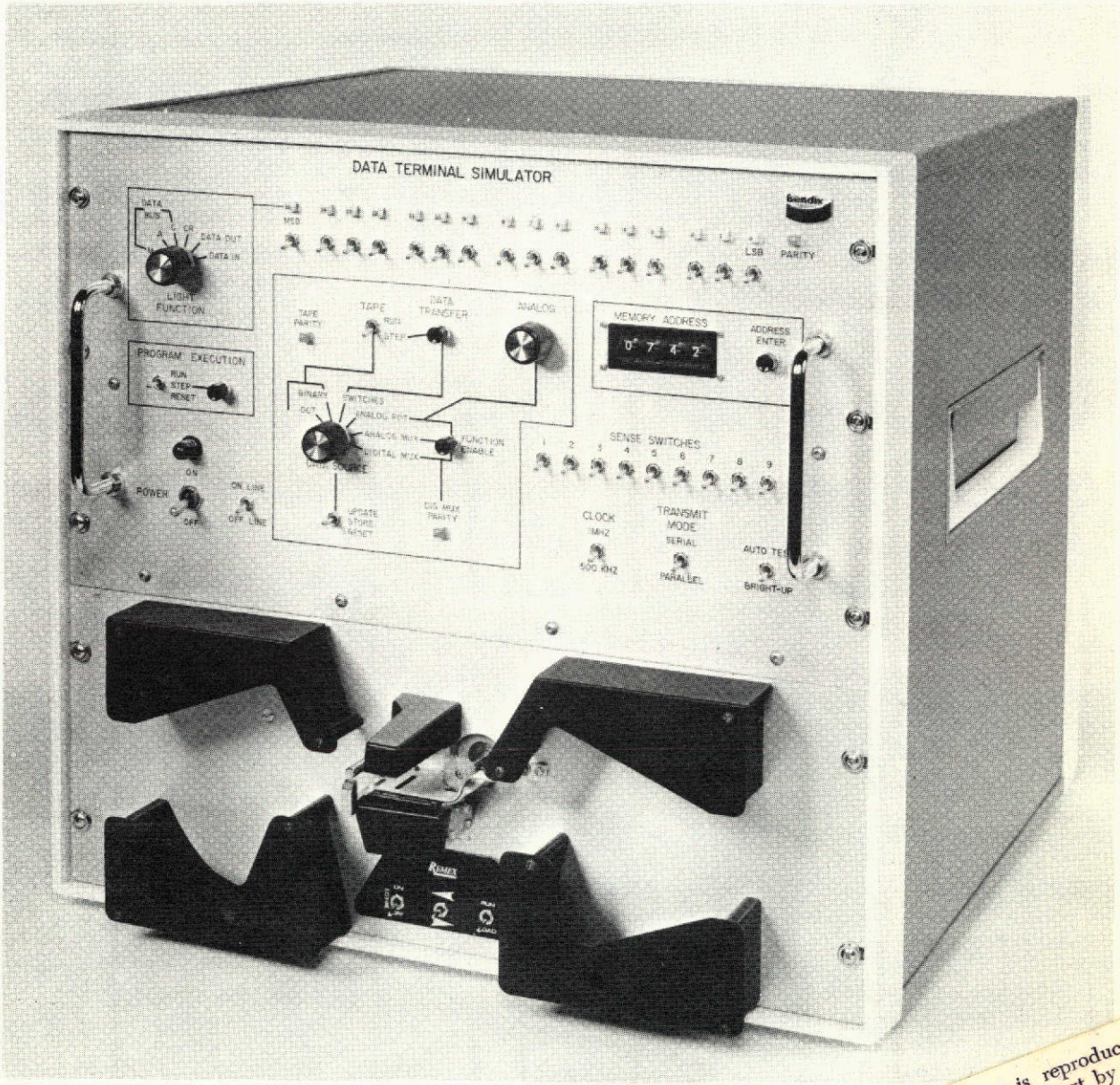
The Display Controller provides the operator with the ability to access any one of the various display modes that are stored in the remote computer memory. The flexibility of the system permits the display of more modes of information than can be stored in the 4096 words of addressable memory in the Symbol Generator. Program instructions for each mode are thus stored in blocks in the mass memory of the computer. The output of the Controller is sent by the Interface to the computer requesting a specific format be loaded into the Symbol Generator memory. The format is sent as a Program Store transmission, and that mode is drawn until a new format is requested.

2.5.2 MAJOR CHARACTERISTICS

The twenty button keyboard of the Display Controller is functionally divided into three sections for mode, number, and control entries. The fourteen mode buttons are decoded into a four bit word with the codes shown in the table below.

Mode	Code	Mode	Code
HSI	0001	ECLS	1000
EADI	0010	ELEC	1001
TRJ	0011	HYD	1010
ABES	0100	MPS	1011
ACPS	0101	SP1	1100
APU	0110	SP2	1101
CYRO	0111	TEST	1110

The data from the four number keys is encoded as a two bit binary word. Each of the control buttons, CLEAR and SEND, is decoded separately and sent to the Symbol Generator. A delayed strobe signal is generated whenever any button is depressed to remove the contact bounce of the keyboard.



Data Terminal Simulator/Input Loader

Figure 2-16

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2.6 DATA TERMINAL SIMULATOR/INPUT LOADER

2.6.1 GENERAL

The Data Terminal Simulator/Input Loader provides a means for off-line loading and testing of the Programmable Multifunction CRT Display System. The PMDS is designed to accept data according to the Shuttle Breadboard Control and Display/Data Bus Interface Definition Document 40M35746. This interface document describes both a serial and a parallel data channel with either operating at one of two data rates, 1.0 Mega bits per second or 500 Kilo bits per second. In addition to simulation of all four of the above modes of data transmission, the Simulator provides test inputs to and readouts from the PMDS that allow the operator to perform a complete system checkout and to debug software programs.

For Symbol Generator testing, the Simulator provides controls for RUN, SINGLE STEP (one instruction at a time), and RESET. During the single stepping operation, the data that is present on any of the four data buses, M, C, A, and CR, can be observed on the lights of the Simulator. An Auto Test/Bright Up switch can be used to show on the CRT the output of the automatic testing routine of the Symbol Generator.

The Simulator has provisions for five different methods of data entry. A set of sixteen toggle switches is used for loading binary coded words one at a time. A paper tape reader can be used to load data from tape punched in either of two formats, octal or binary.

A continuously variable input is provided by an A to D converter driven by a ten turn potentiometer. Two back panel connectors allow entry from other systems. The Digital Multiplexer inputs accepts sixteen bit words which contain four bits of address (0 to 15) and twelve bits of data. The Analog Multiplexer accepts sixteen individual analog inputs. These signals are converted to twelve bit binary words by the A to D. Each word is assigned to a specific location in the Symbol Generator memory. A Memory Address selector is provided for the data from the toggle switches or the analog pot when the simulator is in the update mode. A relay permits switching the system "on-line" or "off-line". When the system is operating off-line, the Simulator provides all interface control. In the on-line mode, all signals are switched to a rear connector that may be plugged into a Data Terminal or another similar interface.

The front panel of the Simulator has nine sense switches that are used for decision making within a software program. Just below the sense switches are the controls for parallel or serial mode and 1.0MHz or 500KHz clock switching.

2.6.2 MAJOR CHARACTERISTICS

Interface, Serial and/or Parallel	40M35746
Data Sources	
Punched Paper Tape	Octal/Binary
Digital Toggle Switches	16
Analog (continuous adjust)	10 turn pot
Memory Address Select	Octal Thumbwheel
Analog Multiplexer	16 Channels
Digital Multiplexer	16 Channels
Display Mode Control	
Update	Dynamic Data
Store	Static Load
Generator Test Mode	
Run	Normal Operation
Single Step	For Diagnostics
Reset	Initialize
Simulator/Loader Mode Control	
On Line	Connected to DMS
OFF Line	Remote Operation

SECTION 3
DISPLAY DESCRIPTION

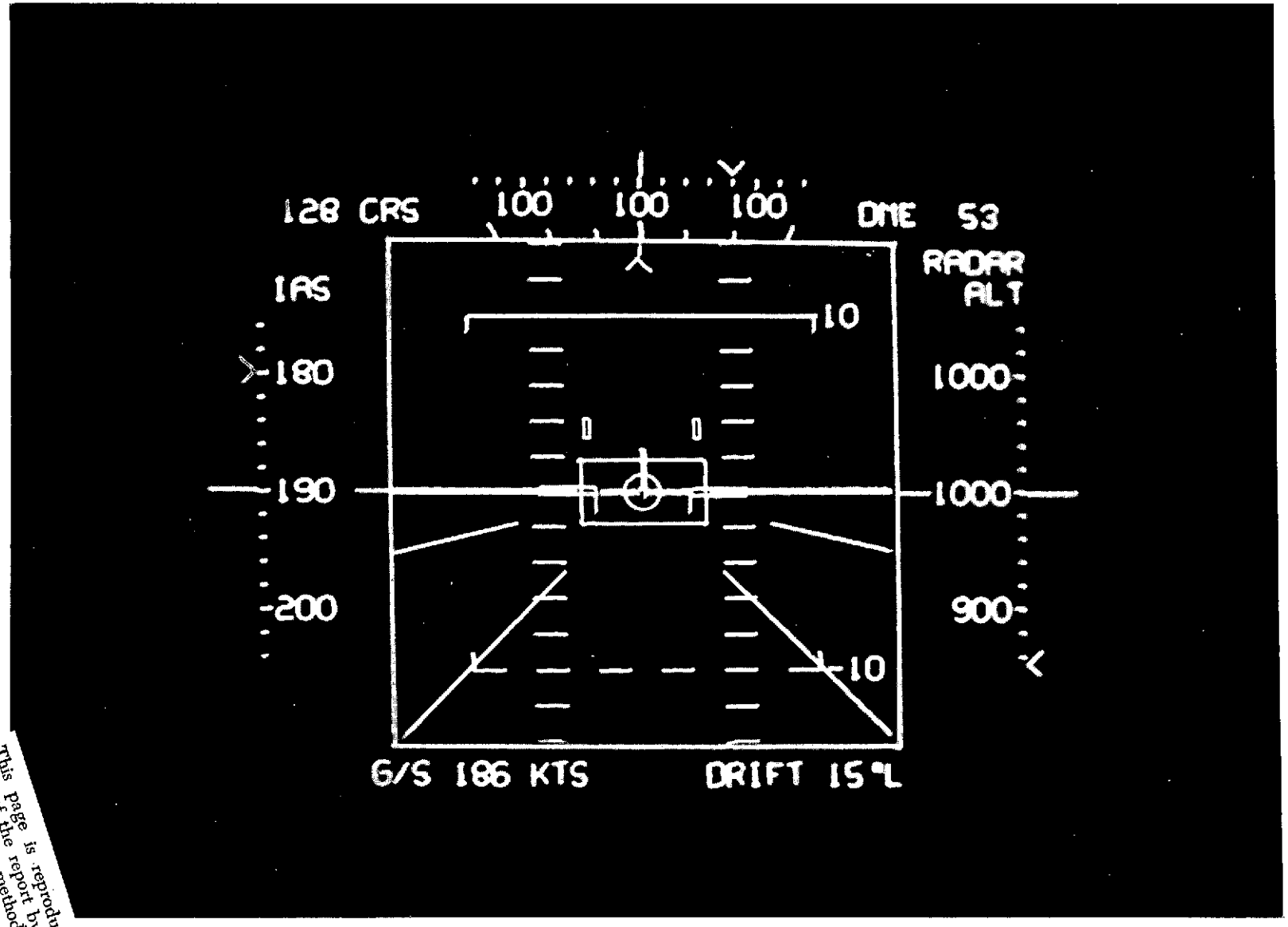
3.1 INTRODUCTION

The Multifunction CRT Display System is capable of displaying lines, vectors, circles, scales, alphanumerics, moving tapes, etc. The Symbol Generator uses this symbology in various combinations to offer different formats for each mode. Changes in format or symbology are easily implemented.

To illustrate the fundamental capability of the Multifunction Display System the subject statement of work required software design and implementation of five typical displays as follows:

Electronic Attitude Director Indicator
Horizontal Situation Indicator
Performance Chart Mode
Mach-Altitude
Vertical Scales

In addition to the programs listed above which can be stored in the read/write memory, a Self Test display is available which is stored permanently in a ROM. The following sections describe each display separately. For greater detail refer to applicable software program documents, listed in Section 1.5 of this report.



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Electronic Attitude Director Indicator Display

Figure 3-1

3.2 ELECTRONIC ATTITUDE DIRECTOR INDICATOR

This program will display an Electronic Attitude Director Indicator (EADI) as shown in Figure 3-1. It has been based upon Figure 2 of Exhibit "A" of the subject contract. The display requirements for the McDonnell Douglas version of the Space Shuttle and the Boeing SST were also considered,and several features of those displays have been incorporated. In addition, consultations with several active experimental and airline jet pilots were held to obtain inputs based upon their experience.

The program,as presently written, will display the following information:

Aircraft Reference Symbol - This symbol serves as a reference for interpreting pitch, roll, flight command error, airspeed error and deviation.

Heading - A continuous 360^{o} moving scale with 2^{o} markers indicates heading relative to a central lubber line. Numerals are displayed at major graduations every 10^{o}. A moving pointer is provided to indicate selected course or heading. Motion of the pointer is limited to remain within the visible portion of the scale. A digital readout of selected course is provided.

Airspeed - A moving vertical scale is displayed covering Indicated Airspeed (IAS) through a range of 0 to 650 knots as read against a horizontal scan lubber line. Numerics are shown every 10 knots with markers at 2 knot intervals. A moving pointer is provided to indicate command airspeed.

The motion of the pointer is limited to remain within the visible portion of the scale. Airspeed error markers are also provided with reference to the Aircraft Reference. The motion of these markers is also limited. The Airspeed error markers and the command airspeed pointer will blink if the aircraft is outside a preset range.

Altitude - A moving vertical scale is displayed covering Radar Altitude through a range of 0 to 5,000 feet as read against a horizontal scan lubber line. Numerals are shown at major graduations every 100 feet with markers every 20 feet. A moving pointer is provided to indicate minimum decision altitude. Motion of the pointer is limited to remain within the visible portion of the scale. This pointer will blink below minimum decision altitude. At 200' altitude a bar representing ground level comes into view and moves toward the Aircraft Reference as altitude approaches zero.

Alpha/Numeric Readouts - Four locations are provided for alpha/numeric blocks of data. As shown, these blocks are used to display 128 CRS, DME 53, G/S 186 KTS, and DRIFT 15^{o}L.

Flight Command Symbol - A "fly to" integrated roll and pitch command symbol (inverted tee) is provided relative to the aircraft reference.

Attitude - Pitch and roll attitude are displayed throughout $\pm 180^{\circ}$ of roll and $\pm 90^{\circ}$ of pitch. Roll reference marks are provided at 0°, $\pm 10^{\circ}$, $\pm 20^{\circ}$, $\pm 30^{\circ}$, and ± 90. Pitch markers are provided every 2° with bars and numerics every 10°. UP and DOWN are displayed at $+90^{\circ}$ and -90° pitch, respectively.

Horizon and Ground Line - The horizon is emphasized and perspective ground lines are displayed for ease of interpretation.

Deviation - A rectangle is displayed relative to the aircraft reference to indicate both vertical and horizontal deviation from a desired path such as the ILS glide slope and localizer. The size of the rectangle and its deflection sensitivity are set to correspond to the maximum tolerable deviation at the minimum decision altitude. At that altitude, the rectangle will blink.

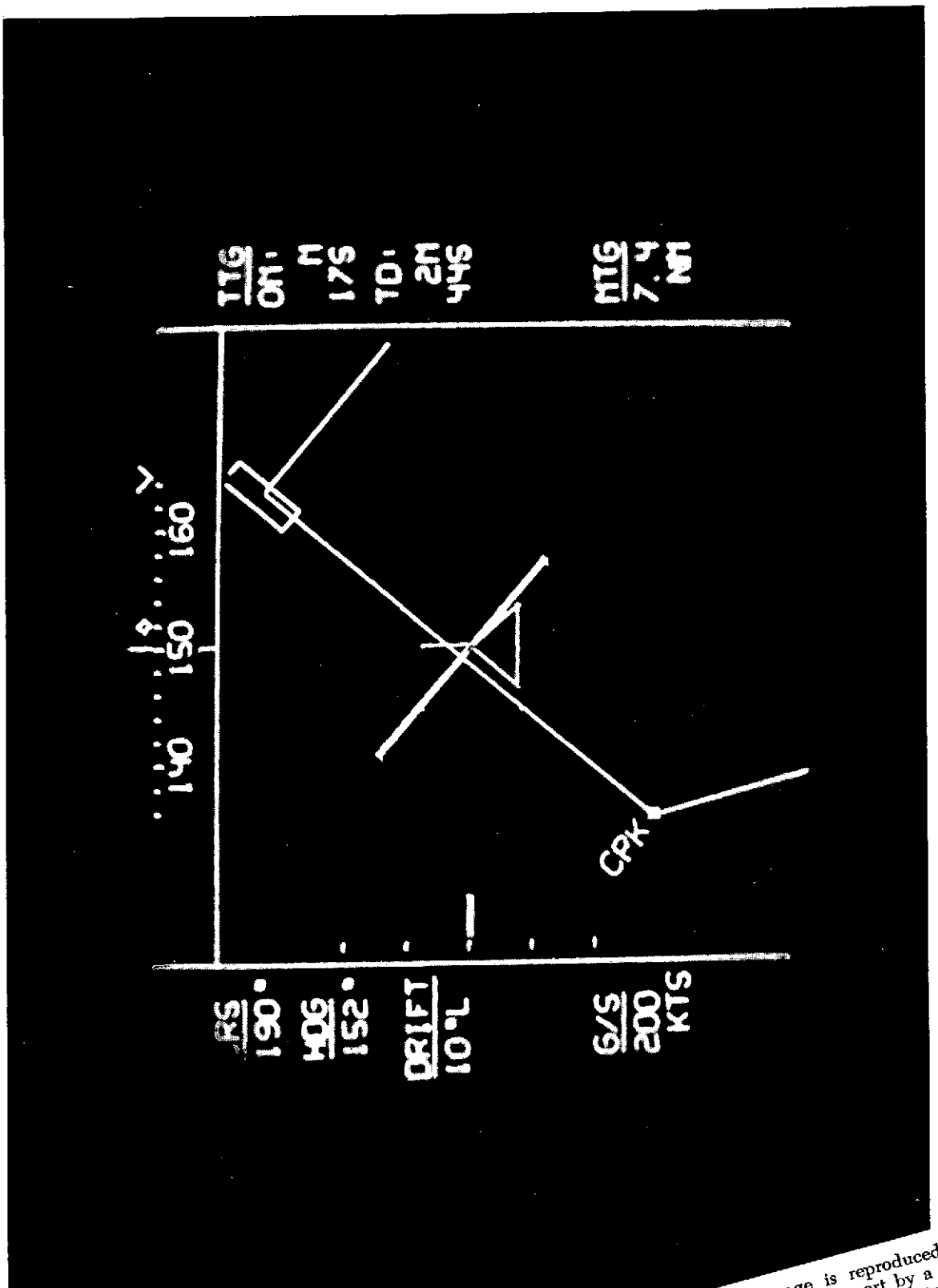
Event Markers - Two different size circles are provided to indicate events such as passing through the outer and middle markers during an approach. Normally, these circles would be blanked until passing through the marker position. At that time, the particular circle would blink, i.e., small circle for outer marker, large circle for the inner marker.

The program has been written in an extremely flexible manner to allow changes to be made by simply modifying input data. Typical modification examples might include, but not be limited to the following:

Scales - Size and number of graduations may be varied. Dynamic range of speed and altitude scales may be expanded with corresponding change in scale factors.

A/N Blocks - The number of A/N blocks and the information contained within the blocks may be varied.

Declutter Control - Specific symbols may be removed or displayed as a function of an input data word.



Horizontal Situation Indicator Display

Figure 3-2

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3.3 HORIZONTAL SITUATION INDICATOR

A program for a Horizontal Situation Indicator Mode (HSI) will produce the display shown on Figure 3-2. It has been based upon Figure 3 of Exhibit "A" of the subject contract. Several experimental and airline jet pilots were consulted to gain the benefits of their experience in establishing this display. As shown on the drawing, the HSI is in the final approach phase, and as presently written, the program results in the following information being displayed:

Map - A map of the approach area is displayed showing the location of specific points such as the CPK waypoint, outer marker, inner marker, minimum decision altitude and runway, all relative to, and at the proper bearing and distance, from the aircraft.

Heading - A moving heading scale is read against a vertical lubber line. Moving pointers are provided to indicate selected course and heading.

Lateral Deviation - A single movable bar is shown parallel to the inbound course but displaced laterally from the aircraft to indicate its deviation from that course in a correct pictorial manner. Reference spots are included to provide a quantative measure of deviation.

Vertical Deviation - Vertical deviation is indicated by both the fixed scale with pointer and a bar perpendicular to the inbound course. This latter bar provides a vertical deviation indication within the pilot's fovial vision while the pointer read against the scale remains in a position uneffected by aircraft heading changes.

Alpha/Numeric Data - Two vertical sectors are provided to display alpha/numeric information. As shown in the figure CRS (course) 190 HDG (Heading) 152°, DRIFT 10°L and G/S (ground speed) 200 KTS are shown on the left. TTG (time to go) OM (outer marker), M (minutes), 17S (seconds), TD (touchdown), 2M, 44S and MTG (miles to go), 7.4 NM are shown on the right.

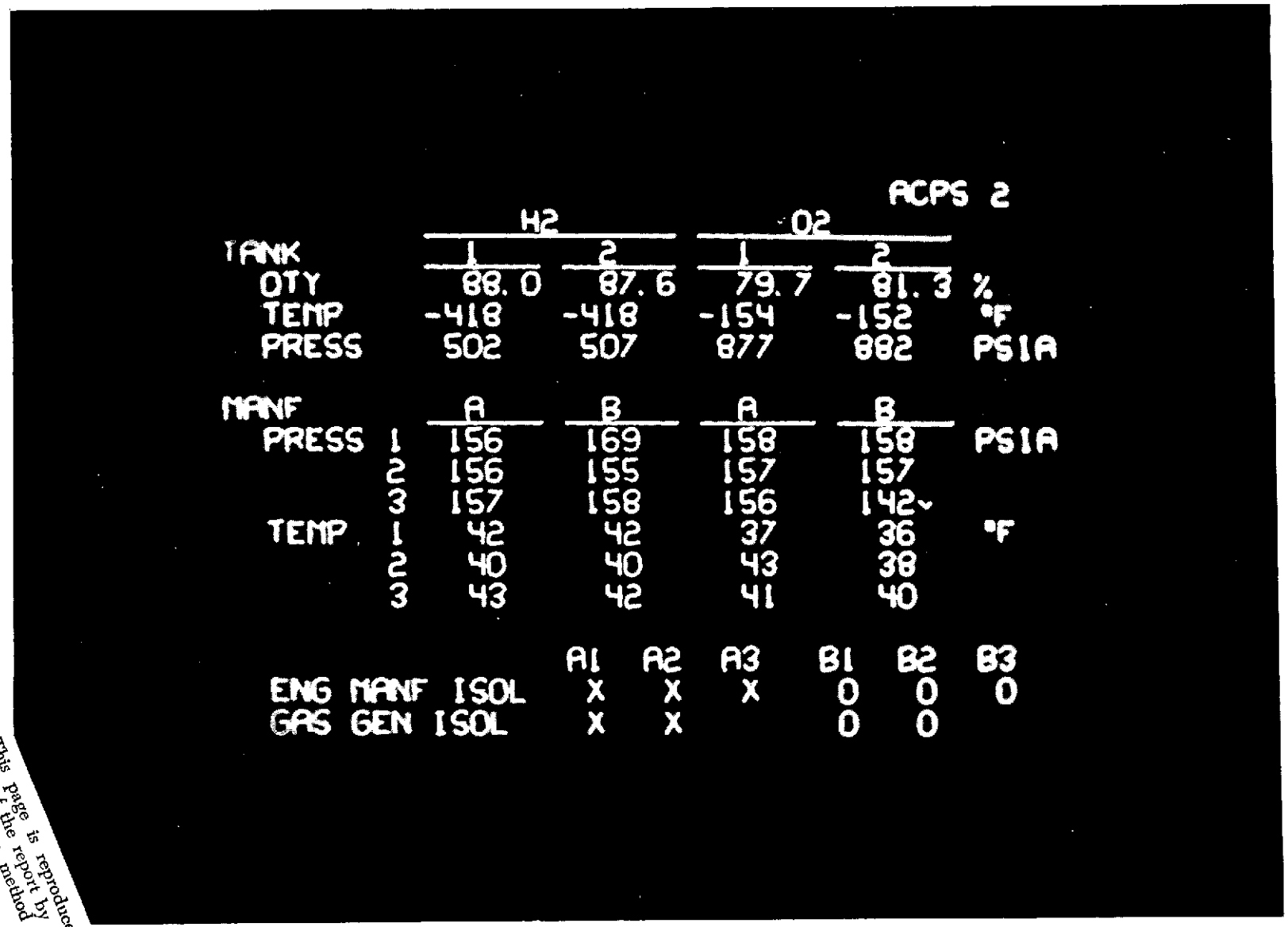
Due to the program's flexibility, changes may be made by simply modifying input data. Typical changes might include, but not be limited to, the following:

Map Details - Additional map details such as waypoints, check points, VOR's, dangerous areas, etc., may be added as required.

A/N Data - The A/N data sectors may be varied to display any required A/N data.

Flashing Symbols - Specific symbols may be flashed at any rate to indicate critical events.

Declutter - Specific symbols may be blanked or displayed as a function of an input data word.



Performance Chart Mode Display

Figure 3-3

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3.4 PERFORMANCE CHART MODE

A program has been written to display a full page of alphanumeric characters or miscellaneous symbols. As shown on Figure 3-3, a Performance Chart Mode is generated based upon Figure 4 of Exhibit "A", End Item Description of Multifunction Display System.

As presently written, the program will handle 18 horizontal lines of 42 size 0 characters per line for a total of 756 characters. In addition, underlines may be drawn as required for emphasis of particular parameters.

The program is flexible and may be easily modified to accommodate such variations as:

Additional Characters

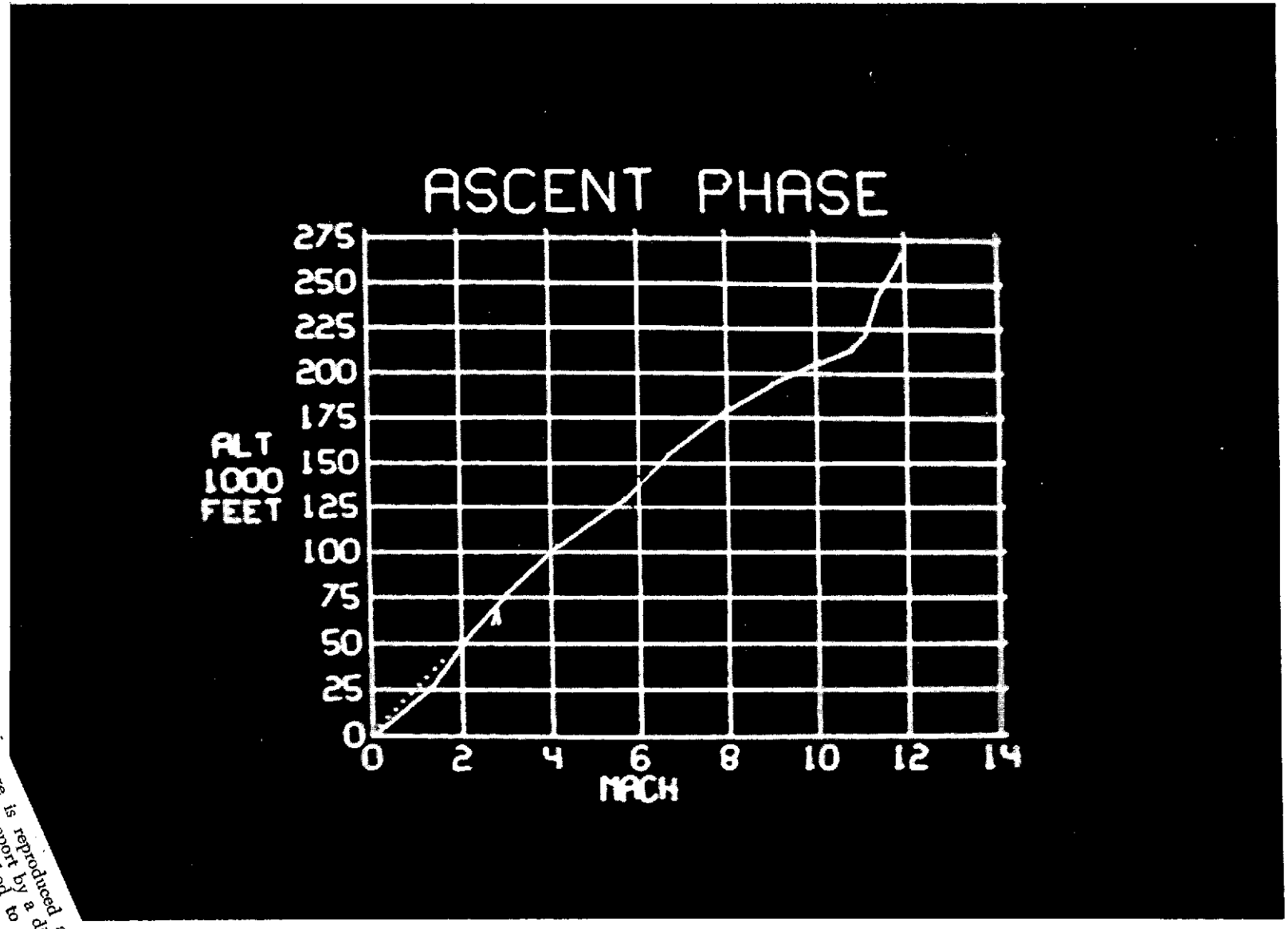
The character/line matrix may be expanded to include up to 92 additional Size 0 characters along the outer edges of the display.

Large Characters

Large characters may be included if required for major titles, etc.

Flashing Symbols

Flashing warning symbols may be included if required.



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Mach-Altitude Display

Figure 3-4

3.5 MACH ALTITUDE

A program has been designed to present a Mach Altitude profile as shown in Figure 3-4.

A single curve is shown, made up of a series of vectors, to represent commanded Mach versus Altitude during ascent. A similar curve is provided during descent. Instantaneous Mach versus Altitude situation is shown continuously during ascent or descent at the point of the chevron symbol. Past history is also presented as a series of dots to indicate trends or rates.

The program has been written in an extremely flexible manner to allow changes to be made by simply modifying input data. Typical modification examples might include but not be limited to the following:

Labels - Quantity, length, position, specific alphanumerics and their size may be changed. Thus, any two related variables may be displayed in this graphical form.

Scale Designations - Up to three digits may be displayed adjacent to any grid line. It is also possible to eliminate digits at any particular line or lines.

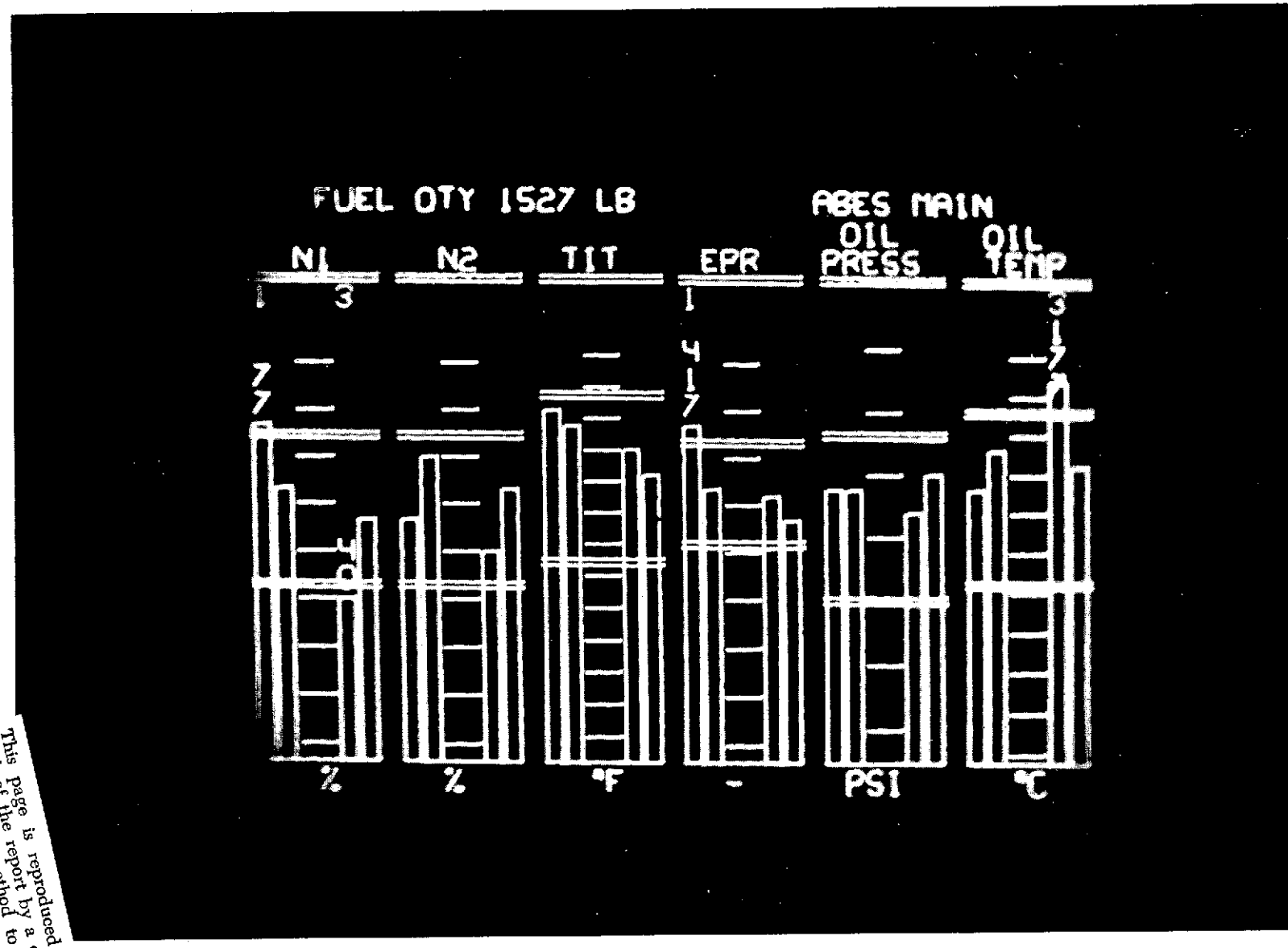
Grid Lines - The quantity and length of all grid lines may be varied.

Command Curve - The number of vectors necessary to describe a particular curve may be varied.

Situation - Situation inputs (actual Mach versus Altitude in this case) may be inputted in equal or non-equal increments of time, mach, or altitude. The situation history may be displayed or eliminated as required.

Ascent/Descent - As a function of an input ascent/descent (AD) data word, the mode changes to display the appropriate ASCEND or DESCENT label, command curve, and chevron orientation. With the exception of AD and instantaneous situation data, it is not necessary to transfer new information into the MDS memory as the mode changes from the ascent to the descent phase.

Additional Symbology - Considerable time and memory space is available to allow additional symbology to be displayed such as a Mach - Altitude safe flight envelop, etc.



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Vertical Scales Display

Figure 3-5

3.6 VERTICAL SCALES

A program has been written to present a Vertical Scale Mode as shown in Figure 3-5. It has been based upon Figure 6 of Exhibit "A" of the subject contract.

With the exception of the warning indications, the display is identical to that in Exhibit "A" adjusted in size, however, to fit the 5 x 7 inch CRT format. The addition, a double row of alphanumerics is necessary to label certain parameters such as OIL PRESS and OIL TEMP.

The program as presently written includes the following features:

- A single row of up to 40 characters may be displayed above the vertical scales. (As shown, it is used to indicate fuel quantity and ABES MAIN).

- A total of 12 characters (2 rows of 6) may be used to label each parameter.

- The upper and lower limits of each parameter may be varied independently.

- When a particular vertical bar indicator is outside the limits, the actual numeric value is displayed just above the bar with up to 3 digits. A flashing bar number is displayed below the label and above the particular bar.

- Up to 6 characters may be used below the bars to describe the particular parameter (%, PSI, etc.)

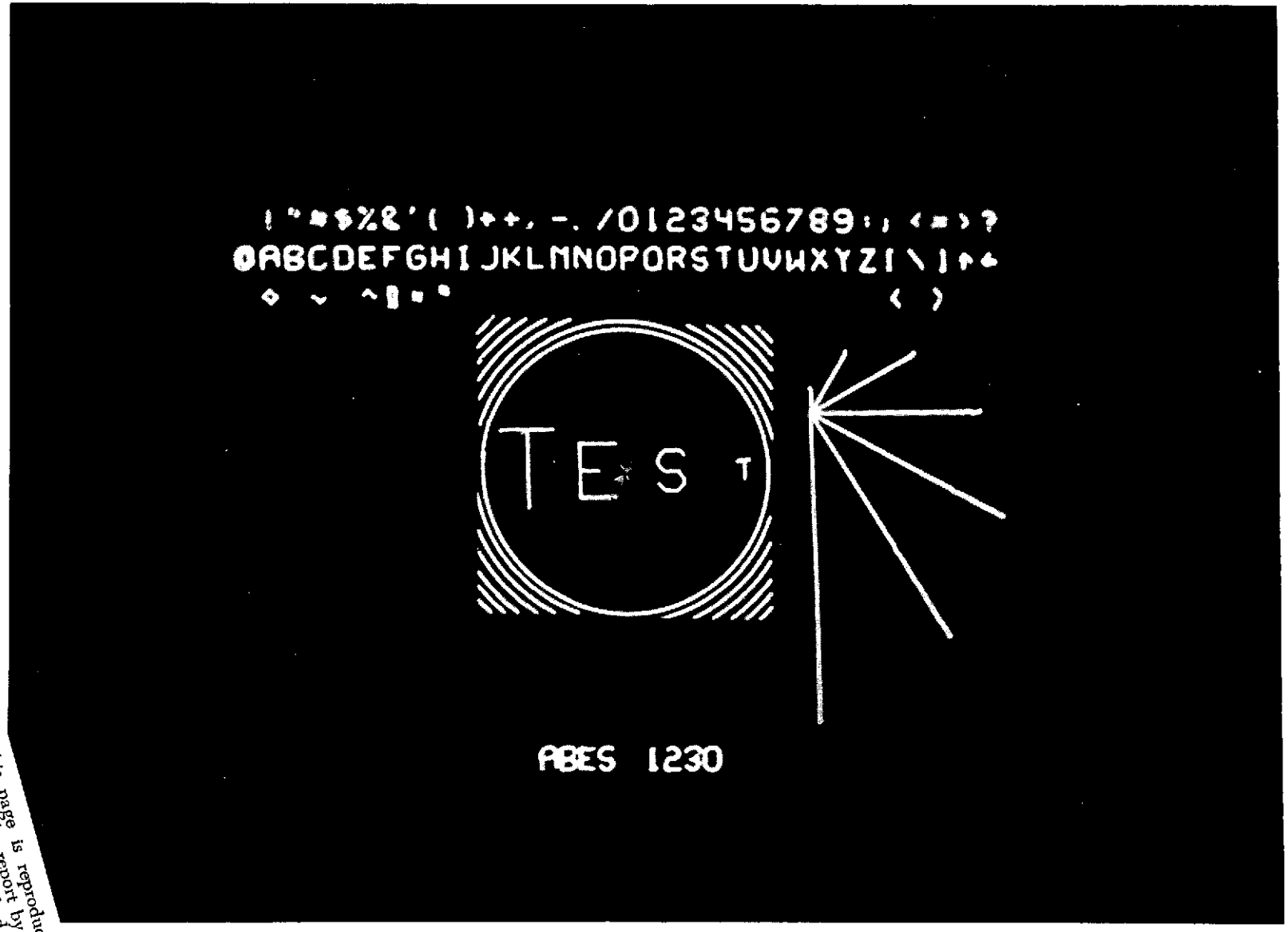
The program has been written in an extremely flexible manner to allow changes to be made by simply modifying input data. Typical modification examples might include but not be limited to the following:

- Parameters. Number of displayed parameter may be varied.

- Bar Indicators. Number of bar indicators displayed for each parameter may be varied. To increase, however, it would be necessary to reduce the number of parameters displayed.

- Scale Height. Scale height may be reduced to allow additional alphanumeric information to be displayed.

- Index Markers. Number and spacing of index markers may be varied. In addition, numerics may be added if required.



Self Test Display

Figure 3-6

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3.7 SELF TEST

The Self Test display is permanently stored in the Symbol Generator so that it is always available by activation of the Self Test Switch. This display provides the operator with a confidence type presentation which includes all basic symbol capability. See Figure 3-6. The display includes:

Full alphanumeric character set
Alphanumerics at 4 different sizes (TEST)
Vector (through all possible angles)
7 fixed vectors at various angles and length
7 concentric circles inscribed within window.

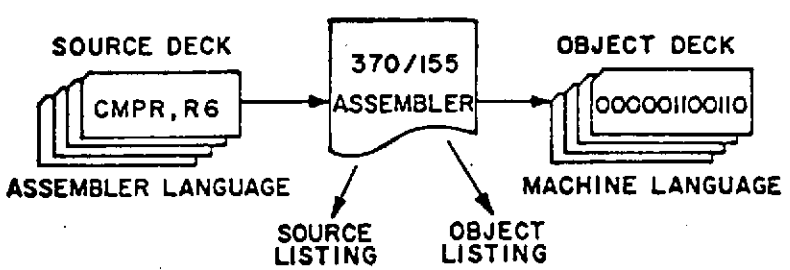
SECTION 4
SOFTWARE PROGRAMMING

4.1 INTRODUCTION

This section briefly reviews software aspects of the Multifunction Display System. Complete details are available by reference to the Programmers Reference Manuals (1. Assembly Level and 2. Machine Level).

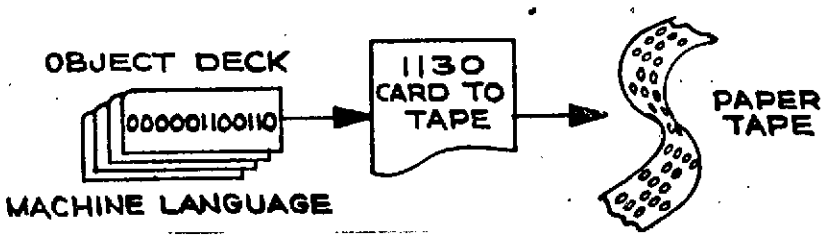
4.2 ASSEMBLER DESCRIPTION

The Multifunction CRT Display System, Relocatable Assembler Program allows a programmer to design display software in convenient assembler language rather than directly in machine language. The instruction code conversion program has been written in Fortran for use in a batch processing mode on an IBM 370/155 computer. The output of this program is a punched deck consisting of one card for each line of assembler source instruction. Each output card contains the resultant 12 bit binary word for each instruction. The Relocatable Assembler also provides the capability of obtaining a hard copy listing of the source information and output deck.



The conversion program is written in basic Fortran and therefore, should be capable of running on any computer, with a Fortran compiler, and a minimum of 110K bites of storage available. The routine uses two scratch areas. However. this can be modified for systems with direct access device capabilities. The program employs a semi-free format input, the first word of each instruction being a fixed (A4) format. Each line of the instruction set is scanned and the corresponding binary code is placed in its proper bit position.

For 370/155 systems with punched paper tape capabilities, the resultant 12 bit instruction/data word can be output directly on paper tape. If this option is not available, the object deck can be read and converted to a paper tape on an IBM 1130 computer or equivalent.

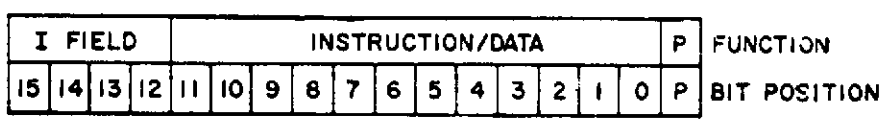


Since 8 hole punch paper tape provides a 7 bit-data, 1 bit parity word per character, it is necessary to divide the 12 bit instruction/data word into two 6 bit words. Bits 1 through 6 of the first punched character corresponds to bits 0 through 5 of the instruction word. A 0 is inserted in bit 7 of both punched characters. The 8th bit of both characters is even parity. The final object tape consists, therefore, of two characters for each line of instruction. At the start of the tape, a 12" minimum blank section is followed by a minimum of 50 rubouts prior to the actual program.

4.3 PROGRAM INPUT

Program input to the CRT display system consists of two modes: 1. Program Store and 2. Variable Update. The Program Store mode loads the Symbol Generator Memory with information required to produce a specific display. Each word is loaded in sequence in direct correspondence to the desired memory location. The Variable Update mode is used to update dynamic data points initially stored as part of the display program. Variables are updated by word pairs: address word and data word.

The input word format is given below.



The input word consists of 17 bits. The least significant bit is a parity bit. Bit P provides odd parity for the total of seventeen bits. Bit positions 15, 14, 13 and 12 designate the state of the I field. Bit positions 11 through 0 are used for data or instructions.

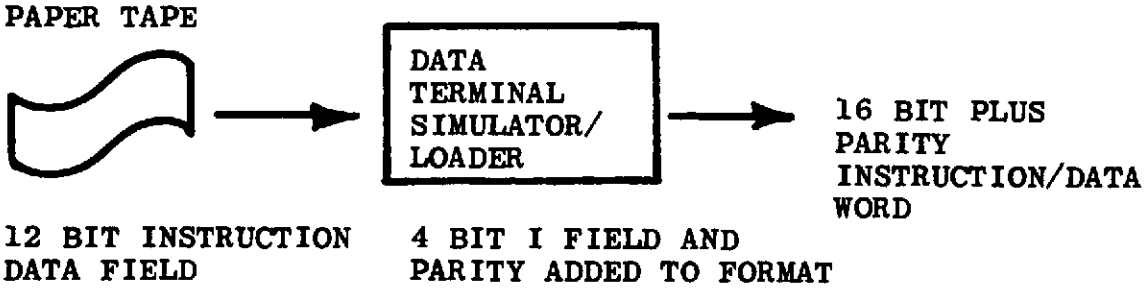
The 4 bit I field identifies the type of transmission between the CRT Display System and the external interface. Code assignments are as follows:

Function	B_{15}	B_{14}	B_{13}	B_{12}
Address Word	0	0	0	0
Data Word	0	0	0	1
Program Word	0	0	1	0
Program Mark	0	0	1	1
Interrogate	0	1	0	0

Bit positions 11 through 0 shall be used for Data or Instruction words. These 12 bits will be stored in the Symbol Generator Memory to control the operation of the generator over the internal C bus. The twelve bits are considered Instruction/Data words internal to generator and can be classified into five types.

Data Words
Memory Reference Instructions
Accumulator - Register Instructions
Input/Output Instructions
Control Operations

The input word can be generated by a minicomputer, central computer complex, data terminal or the Data Terminal Simulator/Input Loader. The simulator/input loader, as the name suggests, offers a paper tape reader for program loading and additional circuitry to provide simulated Symbol Generator input consistent with interface requirements. The paper tape input contains information



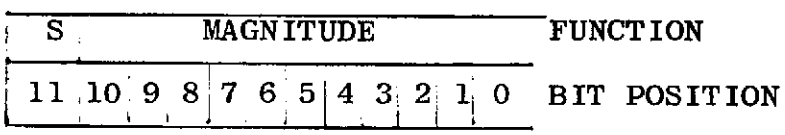
to generate the 12 bit Instruction/Data field. Two tape modes are provided: octal and binary. The octal mode formats the 12 bit field using four tape characters per word. The binary mode employs 6 bits of each tape character so that only two characters per word are necessary.

4.4 DATA STATEMENTS

Data statements are used to represent the value of some input variable, constant, or screen position. It could be vector angle or magnitude, circle diameter, selection of alphanumeric desired, etc.

DATA WORDS - GENERAL

The Instruction/Data field provides 12 bits to specify information. Thus the data word format, in the general sense, contains 11 bits magnitude plus one bit sign. The data word format is defined below.



The most significant bit (bit 11) represents the sign. Eleven bits are provided for magnitude. If the sign bit (B_{11} = 1) is negative, then the magnitude is represented in two's complement.

SCREEN AREA

The Multifunction Display System has a useful screen area divided into 1024 by 1024 addressable locations, corresponding to a 10 bit x 10 bit system. Thus position, vector magnitude, diameter, bright-up limits, etc. are specified in terms of values from 0 to 8 inches.

LABELS - FOR SINGLE LOCATIONS

Labels may be used to identify a memory location. The label must preceed the data to be stored at the label memory location.

Labels may consist of any combination of alphanumeric characters up to a maximum of twenty.

LABEL - FOR DATA BLOCKS

A label can be used to identify blocks of data which will be stored at the program end. This is accomplished by following the lable with "&" and the number of data statements within the block. The label is actually interpreted as the address of the first memory location of the block.

DATA IN INCHES

Data representing screen position, vector magnitude, or circle diameter is specified in inches. The smallest resolvable element is 1/128" and the maximum dimension is 7 127/128". Data may be entered in fractional or decimal form. If the data is in decimal form, the assembler will select the nearest value possible consistent with a resolution of 1/128".

If fractional data is not divisible into 1/128, the assembler will assign the nearest value possible consistent with a resolution of 1/128".

DATA IN DEGREES

The statement specifying data in degrees is ended by a "D". The angular resolution is $360^{o}/1024$. Angles may be represented in decimal numbers. The assembler program assigns the nearest possible angular value. Angles may be expressed as positive or negative values.

Angles greater than 360^{o} may be specified. The assembler will convert this value to an equivalent value less than $\pm 180^{o}$. For instance, 330^{o} will be assembled into the object deck as -30^{o}. The angle 390^{o} will be assembled as $+30^{o}$.

ALPHANUMERIC DATA

Alphanumeric data is specified by preceeding data with "#". Data must consist of desired alphanumeric followed by comma and size selection.

MULTIPLE NUMERICS

Normally 7 bits are required to generate the proper ASCII code for any numeric. However since the 3 most significant bits of all numerics, 0 through 9, are the same (decomal equivalent 48) the following algorithm may be employed with a possible saving in memory space. Three size 0 numerics can be specified as follows.

(#,2,#,4,#,6,)

The assembler program will format the 4 least significant bits of each numeric into the 12 bit word illustrated below.

1ST NUMERIC				2ND NUMERIC				3RD NUMERIC				FUNCTION
11	10	9	8	7	6	5	4	3	2	1	0	BIT POSITION

The least significant bit of the first, second and third numeric will be in bit positions 8, 4 and 0 respectively. By subsequent software instructions to shift and add 48, each separate alphanumeric word can be generated.

SINE θ/COSINE θ DATA

The assembler program can generate the value of the sine or cosine of any angle (consistent with a resolution of $360^{\circ}/1024$). The sine of an angle is specified by preceding the angle by SIN. The cosine of an angle is specified by preceding the angle by COS.

DATA, INTEGER VALUES

The Instruction/Data Field provides 12 bits to specify information. Thus the data word format, in the general sense, contains 11 bits magnitude and one bit sign. Therefore any integer value between -2048 and +2047 is permissible. No fractional or decimal form is available for general application. Data expressed in inches or angular degrees are exceptions consistent with the preceding paragraphs.

4.5 INSTRUCTION SET

The Arithmetic Control Unit (ACU) provides the essential central processing function of the Symbol Generator. Specific functions are performed as determined by the content of a 12 bit control bus. The ACU processes data words, performs memory referenced instructions, accumulator register operations, input/output instructions, and control operations. In addition, an Auxiliary Accumulator is provided for shifting operations. This capability makes the ACU very useful for testing single or groups of bits that are within a data word. Any of 16 high speed buffer registers can be accessed for the Accumulator Register operations. These Registers are best employed for storing the most frequently used parameters since these instructions require half the execution time of a Memory Reference Instruction. All data operations and transfers are through an Integrated Circuit Arithmetic Logic Unit capable of 16 arithmetic and 16 logic operations.

Memory referenced instructions perform functions between an effective address at some memory location and the accumulator. This instruction set is as follows:

STØ	STORE
LOAD	LOAD
CMP	COMPARE
SUB	SUBTRACTION
ADD	ADDITION
JU	JUMP

Accumulator-register instructions perform functions between the accumulator and one of sixteen auxiliary registers. This instruction set is as follows:

ACM	ARITHMETIC COMPLEMENT
ADDR	ADDITION
SUBR	SUBTRACTION
CMPR	COMPARE
INC	INCREMENT ACCUMULATOR
DEC	DECREMENT ACCUMULATOR
INCR	INCREMENT REGISTER
CLA	CLEAR ACCUMULATOR
CLR	CLEAR REGISTER
TAR	TRANSFER A TO R
TRA	TRANSFER R TO A
STA	SHIFT RIGHT
SLA	SHIFT LEFT
SAR	STORE
LAR	LOAD

Input/output instructions allow for two-way communication between the ACU and any peripheral device. Output instructions generally are between the ACU and Symbol Maker data registers. Input from external interface is done automatically each frame and is not accessible through software. The only other need for input to the ACU is from the keyboard register. The instruction set is as follows:

ØD	OUTPUT DATA
ID	INPUT DATA

Control operations are those instructions which directly affect the operation of the Symbol Generator as a whole. The following control words are available.

SRT	START
SRTL	START LONG
HLT	HALT

SECTION 5

RECOMMENDATIONS

5.1 INTRODUCTION

This section lists recommendations based upon experience and results of efforts expended under this contract. The recommendations can be categorized as essentially product improvements relative to the present system.

5.2 DATA INPUT AT DATA BUS INTERFACE

Information to specify instructions and data necessary to generate a given display is sent to the Symbol Generator over the 40M35746 interface. Data input to the CRT Display System consists of two modes:

1. Program Store
2. Variable Update

The Program Store mode loads the Symbol Generator Memory with information required to produce a specific display. Each word is loaded in sequence in direct correspondence to the desired memory location. The Variable Update mode is used to update dynamic data points initially stored as part of the display program. Variables are updated by word pairs: address word and data word.

The Variable Update mode requires considerable data bus traffic since each data point requires two words; data and address. A more efficient design is possible if updating by variable length data blocks were incorporated.

In a given transmission, the first word would contain the address of the first data variable. The second word would contain the number of words in the data block and subsequent words would contain data. Using this approach would also obviate the need for a separate program store mode since this information would be transmitted in the same manner.

5.3 MULTIPLE FORMAT LOAD

The present software is designed to be stored in the Symbol Generator one display at a time. It would be desirable to provide the capability of multiple format storage up to the capacity of the Symbol Generator Memory. Thus, many displays could be stored and ready for use without requiring extensive data bus traffic. Display call-up could be accomplished using the existing discrete switches or by control code generated over the data bus or keyboard.

5.4 HIGHER LEVEL ASSEMBLER

The present assembler program allows the software designer to specify a display program using a simple language. This language employs mnemonics in a one to one relationship with machine words. Thus, the total number of assembler statements is equal to the number of memory locations required. It would be desirable to develop a higher level assembler or compiler which would allow the programmer to specify the design in short statements. These statements would then be sufficient to generate the more complete listing, using a compiler routine.